Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 2411 - 2424, 2005

DEVELOPMENT OF MULTI-CLASS ASSIGNMENT FOR DYNAMIC ROUTE GUIDANCE STRATEGY

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Abstract : This paper focuses on the development of a dynamic multi-class assignment for evaluation and application of the dynamic route guidance strategy. Travelers are classified into three groups according to information contents which they received before departing or on trip. The first group have no traffic information, so they travel along with fixed route. The second group has real-time shortest path information from travel agency and takes the route. The last group has car navigation system or individual methods such as cell phone, PDA-two way communication for traffic information on trip. So they follow the control of DFS (decentralized feedback strategy) where the control system is operated locally. In order to consider these three groups in a model we propose a multi-class dynamic assignment model. With the proposed model some traffic information strategies are tested and interpreted in terms of ITS (Intelligent transport systems).

Key Words : Dynamic Traffic Assignment, ATIS, Dynamic Route Guidance, DFS, RHI

1. INTRODUCTION

Most of existing strategies of providing traffic information have been concentrated to the part that provides the information of real time shortest path and network information to drivers.

But this identical traffic information provided to the drivers may cause and adverse effects on transportation systems as well as undesirable changes of demand. So, many researches have pointed out that the situations like this can cause unnecessary congestions in the metropolitan cities. (Arnott et al. 1991. Ben-Akiva et al. 1991)

The necessity of researches on multi-class traffic assignment models classifying several heterogeneous traveler groups according to the traffic information has been augmented compared to the researches that assign the traffic after supposing the homogeneity in travelers' characteristics. Also, the researches for accomplishing a realistic traffic assignment by assuming the heterogeneous drivers' group have been increased. But the most of these have modeled such situations just by classifying the groups with traffic information and groups without traffic information. Because these models cannot reflect the realistic traffic flows that correspond to the diverse traffic information authorities and traffic information, they cannot analyze the effectiveness of alternatives according to the various policy considerations of Intelligent Transportation Systems (ITS).

This paper presents a multi-class traffic assignment model that divides the travelers according to the contents of provided traffic information besides the existence of real time traffic information. By this, we suggest a control variable of the model, the core part of the Decentralized Feedback Strategy (DFS) that can correspond to the various demand change and networks. The multi-class dynamic traffic assignment model adopts Rolling Horizon Implementation (RHI) and assesses the application and effectiveness of DFS as an en-route information with in-vehicle equipment.

2. LITERATURE RIVIEWS

The traffic information providing strategies can be divided into Iterative (or Predictive) strategy that puts emphasis on the traffic demands like O-D and DFS (Decentralized Feedback Strategy) which emphasizes the observed link volumes and travel times. Iterative (or Predictive) strategy is based on the prediction of users' reaction according to the provided information (Ben-Akiva et al. 1997). And it's very important element to predict network situations and to generate the contents of route guidance.

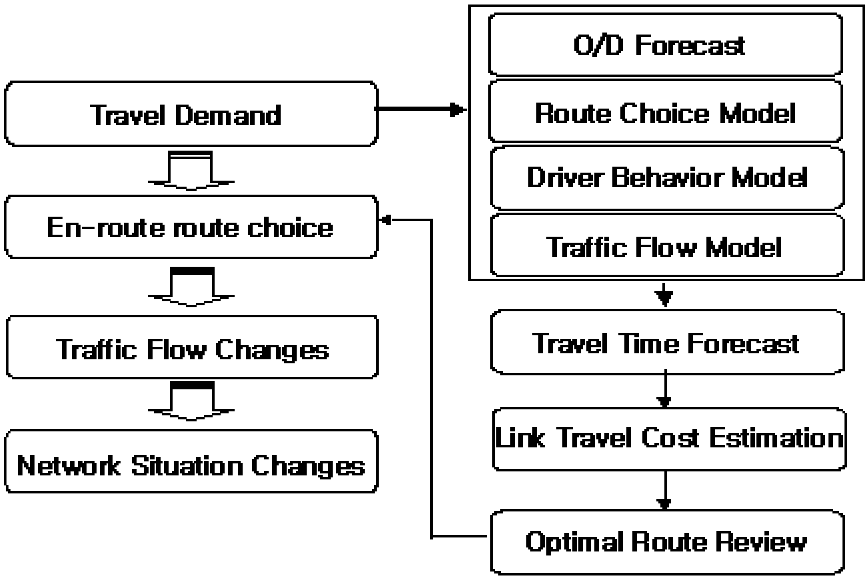

Figure 1. The Process Of Predictive Strategy

But, Decentralized Feedback Strategy is based on the observation of network situations (Papageorgiou and Messmer, 1991 ; Mauro, 1998). In other words, by monitoring the values (volume, density, travel time, etc.) which can be detected directly, we can lead systems to optimal states after controlling the traffic flow at the diverge nodes. By doing this, we can achieve our goal which equalize minimum travel times among alternative routes. From here, we can search all the alternative routes that are needed to travel for destination and this approach can be regarded as an engineering method in that the real time data are more important than the predicted values.

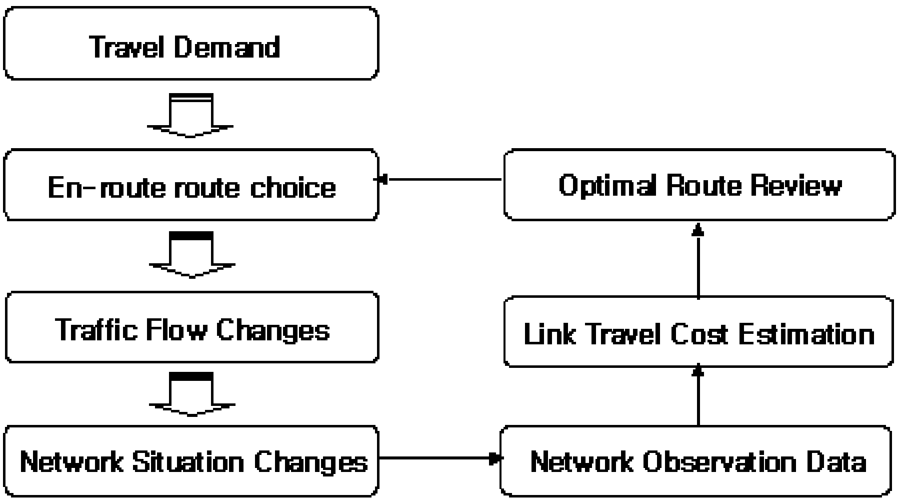

Figure 2. The Process Of DFS

3. FORMULATION OF THE MODEL

The multi-class dynamic traffic assignment model for execution of traffic information providing strategies is achieved by combination of several sub-models such as the model of control value for application of DFS and RHI which performs the traffic assignment of travelers completing the rerouting during special time periods and some special models used for dynamic traffic assignment.

3.1 DFS(Decentralized Feedback Strategy) Model

As described before, the core part of DFS is control values applied to control node. The basic application process of DFS is presented in the following example. $\alpha_{ikD}(t)$ is the rate of volumes arriving destination node, D, via route, k, out of the volumes of link, i, which inflows to node, j, at time t .

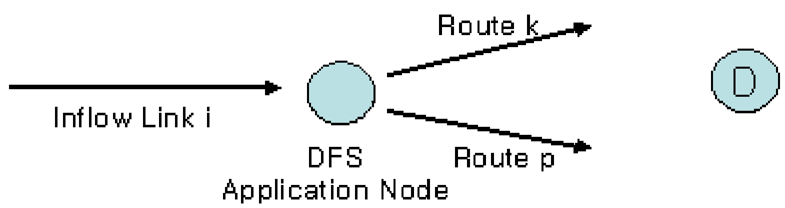

Figure 3. The Concept For DFS Explanation

$$\alpha_{ikD}(t) = f_k^{jD}(t) / T^{jD}(t)$$

$$\text{where,} \quad \alpha_{ikD}(t) + \alpha_{ipD}(t) = 1$$

The control value, α_{ikD}, is set to solve the dynamic stochastic user equilibrium, which can be expressed as followings.

$$f_k^{jD}(t) = T^{jD}(t) \frac{\exp(-\theta c_k^{jD}(t))}{\sum_w \exp(-\theta c_w^{jD}(t))}$$

- $f_k^{jD}(t)$: volumes of route k from DFS application node j to destination node D at time period, t.
- $T^{jD}(t)$: total volumes traveling from DFS application node j to destination node D at time period, t.
- $c_k^{jD}(t)$: cost of route k from control node j to destination node D at time period t.

The positive value of θ in numerical expression means the user's dispersion parameter in selecting routes. As it has been known, the bigger the parameter value is, the problems become closer to deterministic traffic assignment. The control variables are set to have identical perceived travel cost for the routes from DFS application node to destination node, over considering differences of the traffic information which drivers receive. This can be expressed as following equation.

$$c_k^{jD} + \frac{1}{\theta}\ln(f_k^{jD}) = c_p^{jD} + \frac{1}{\theta}\ln(f_p^{jD}) = C^{jD*}$$

If route k and route p is different each other and have route volumes f_k^{jD} and f_p^{jD} respectively, the expression represents that there is an identical perceived travel cost (C^{jD*}), which call "equivalent path cost".

We adopt direct logit loading method of Lim(2003) specifically for the purpose of applying the route based stochastic traffic assignment model. The solution algorithm for direct logit loading method used in this paper is as follows.

[stage 0] Initialization

- Alternative routes are enumerated under reasonable path set
- Initial value setting : initial route travel cost($c_k^{jD}(0)$), travel demand($T^{jD}(t)$), diversion parameter ϕ , iteration number(n)=1

[stage 1] Computing the route travel volume ($f_k^{jD,n}(t)$) using $c_k^{jD,n}(t)$

$$f_k^{jD}(t) = T^{jD}(t)\frac{\exp(-\theta c_k^{jD}(t))}{\sum_w \exp(-\theta c_w^{jD}(t))}$$

[stage 2] Updating the route travel cost

- Updating the route travel cost ($c_k^{jD,n}(t)$) using $f_k^{jD,n}(t)$

[stage 3] Convergence test

- if, $\dfrac{\max\left|C_k^{jD,n}(t) - C_p^{jD,n}(t)\right|}{\max\limits_{w\in W} C_w^{jD,n}(t)} < \varepsilon$, $\forall k \neq p \in W(path\ \ set)$, stop

otherwise, proceed to [stage 1] after n=n+1

3.2 RHI (Rolling Horizon Implementation)

The initial concept of rolling horizon process was utilized for production inventory control. It has been applied in the areas of online demand responsive traffic control for transportation engineering problems. The rolling horizon implementation recognizes that the prediction of origin-destination matrices and network conditions is usually more accurate in shorter period of time. Thus rather than assuming that the time-dependent OD matrices and network conditions are known at the beginning of the horizon, it is more reasonable to assume that the required information will not be available until the time period rolls forward. To solve such limit of existing dynamic traffic assignment model, this paper utilizes RHI which implements traffic assignment repeatedly to update assignment continuously by dividing the time into short term and mid term during specified time period.

For this, traffic assignments are performed by dividing the vehicles into two groups such that the vehicles in one group pass the control node and the vehicles in the other group does not pass the control node. In other words, by comparing roll period with vehicle travel time from origination node to DFS application node, we decide whether the vehicles reroute or not.

- $Roll\ \ Period > t_{ij}(t)$: Implement rerouting of traveler group
- $Roll\ \ Period < t_{ij}(t)$: Not implement rerouting of traveler group
- $t_{ij}(t)$: Travel time from origination node to DFS application node

3.3 Multi-class dynamic traffic assignment model

Multi-class dynamic traffic assignment model performs assignment by classifying the travelers into several classes according to the contents given traffic information. Deterministic queue model is used for a link cost function, which can be expressed as,

$$\frac{dL}{dt}\Big|_{t=t_0} = \begin{cases} 0(L(t_0) = 0, e(t_0 - \phi) \le Q) \\ e(t_0 - \phi) - Q(otherwise) \end{cases}$$

where,

- $L(t)$: Numbers of vehicle in queue at time, t
- ϕ : Free flow travel time
- Q : Capacity of queue.

Because delay caused by arriving vehicles to the queue at time, t, is L(t)/Q, the travel time to destination node at time, t is given as following equation.

$$\tau(t) = t + \phi + L(t+\phi)/Q$$

So travel time is

$$c(t) = \phi + L(t+\phi)/Q\ .$$

Solution algorithm for the multi-class dynamic traffic assignment for assessing the effectiveness of DFS which has been discussed can be summarized as following.

[stage 0] Initialization

- Initial set;

O/D volume / Identification of traveler group / time stage / Time Interval / Roll period / Dispersion parameter (ϕ) according to traveler's route / Initial travel time of link, a, of each route (C_k^{aD})

[stage 1] Traffic assignment during time stage

- Order of assignment : group 1 -> group 2 -> group 3
- Traveler group 1 : loading the volume to the network
- Traveler group 2 : loading all the volume to the dynamic shortest route (using travel time during time period, n-1)
- Traveler group 3 : loading route volume to meet DSUE by DFS

[stage 2] Computing the link travel time of each route

$$c_p^{iD}(t) = \sum_a [\phi_a(t) + L_a(t+\phi) / Q_a(t+\phi)]$$

- Repetition of the travel time updating process after analyzing the capacity of link a ($Q_a(t)$) and number of vehicle link a in queue($L_a(t)$) at time interval, t, throughout the volume of link, a,($f_{pa}^{iD}(t)$) of route, p, from i to D

[stage 3] Move of time interval (t)

- After moving the time interval during time stage, compare time interval with Roll Period
- If analysis time period < Roll Period, then go to [stage 1] and repeat

  Otherwise, go to [stage 4]

[stage 4] Implementation of DFS

Analysis of volume which do not terminate its trip from origin to DFS application node during Roll Period.

Setting the control value

- DSUE

$$f_k^{jD}(t) = T^{jD}(t) \frac{\exp(-\theta c_k^{jD}(t))}{\sum_w \exp(-\theta c_w^{jD}(t))}$$

- Calculate $\alpha_{ikD}(t) = f_k^{jD}(t) / T^{jD}(t)$

[stage 5] Rolling Horizon
- If Roll Period reaches the end of final time interval, stop
- Otherwise, go to [stage 1] and repeat the assignment

4. APPLICATION TO AN EXAMPLE NETWORKS

4.1 Example network

The example network has 7 nodes and 8 links for one OD pair from node 1 to node 7, where node 4 represents DFS applied node. The network specifications are given in Table 1.

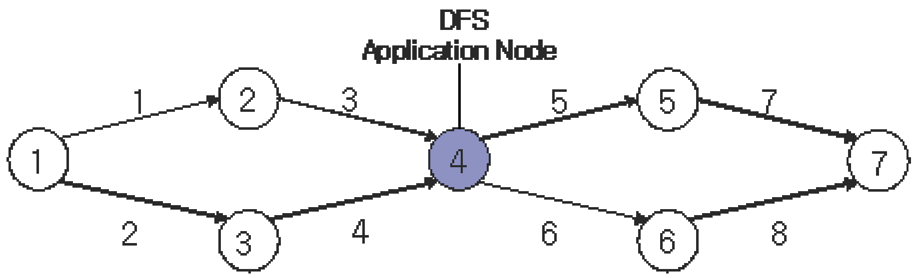

Figure 4. Example Network

Table 1. The Attributes Of Each Link

Link Number	Free Flow Travel Time(MIN.)	Capacity (veh/30sec)	Link Number	Free Flow Travel Time(MIN.)	Capacity (veh/30sec)
1	2.1	30	5	2	15
2	3.1	40	6	2	20
3	3	25	7	4	20
4	3	25	8	3	10

- Route 1 : 1-3-5-7
- Route 2 : 2-4-5-7
- Route 3 : 1-3-6-8
- Route 4 : 2-4-6-8
- Time increment : 30 sec
- Dispersion parameter : 0.028
- Time interval : 20
- Time stage : 10
- Roll period : 5 min.
- Group 1 : 20%
- Group 2 : 30%
- Group : 50%
- Inflow rate : 30veh / 30sec
- An accident occurred at link 5 in time interval from 1350sec to 1650sec, is expressed as capacity reduction on that link to a half.

4.2 Numerical results

Figure 5 though Figure 7 show flows of each link before and after applying DFS. At first, each link (link 1 ~link 4) has nearly same flow before and after applying DFS, because there is no congestion among those links. But there is some difference in the side of flow for link 5

~ link 8 before and after DFS, which is caused by the rerouting of group 2 and group 3 at DFS application node. For examples, the decrease of inflow at link 6 happens from 990sec before DFS, while the decrease happens from 690sec after DFS. So, the inflow of each route changes and the decreasing point of route 3 has changed from 660sec to 300sec.

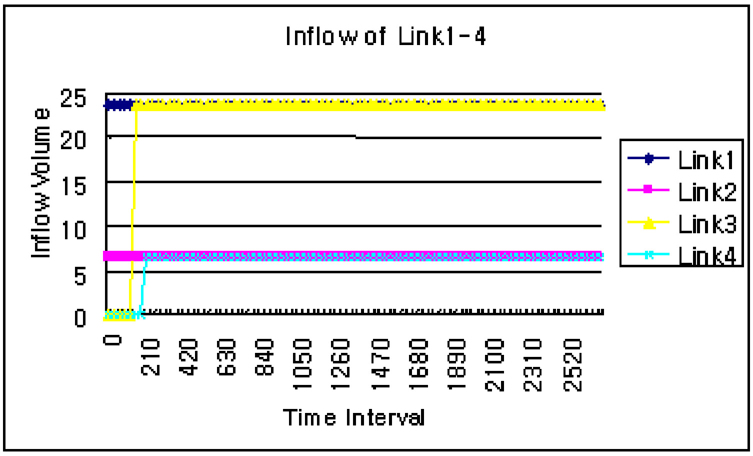

Figure 5. Flow Of Link 1 ~Llink 4

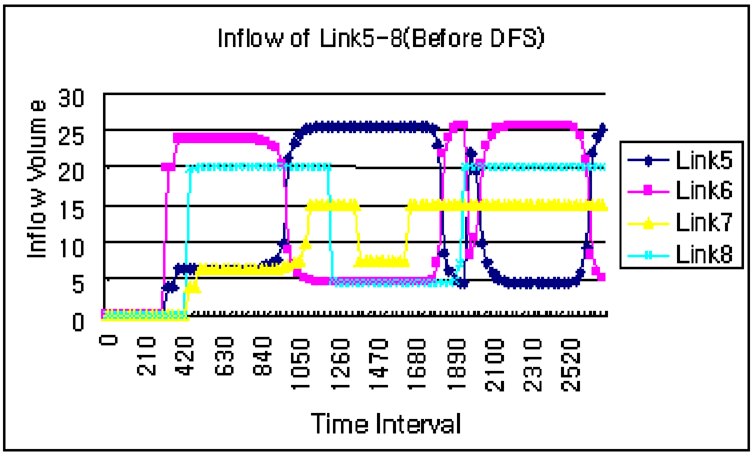

Figure 6. Flow Of Link 5 ~ Link 8(Before DFS)

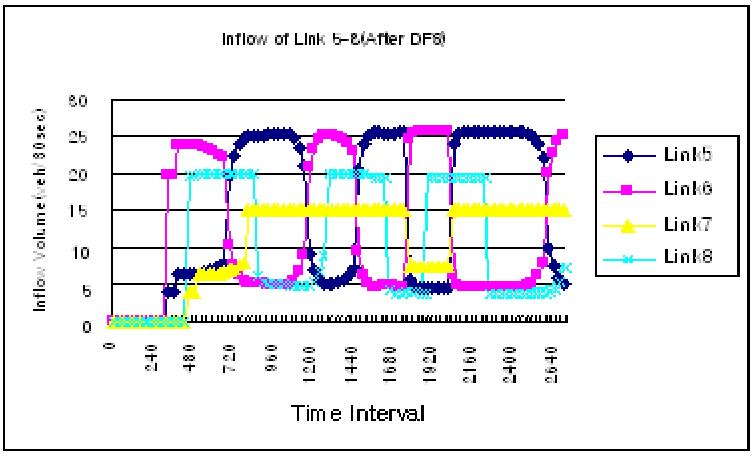

Figure 7 Flow Of Link 5 ~ Link 8(After DFS)

The equivalent path costs are presented in Figure 8 and Figure 9. Figure 8 is the equivalent path cost for the overall 4 paths before DFS and <Fig. 9> is the equivalent path cost for 2 paths from DFS application node to destination. The figures show that the equivalent path costs for each path are not identical, because the flow of group 1 and group 2 does not follow the equilibrium principle. Note here that only group 3 follows the principle.

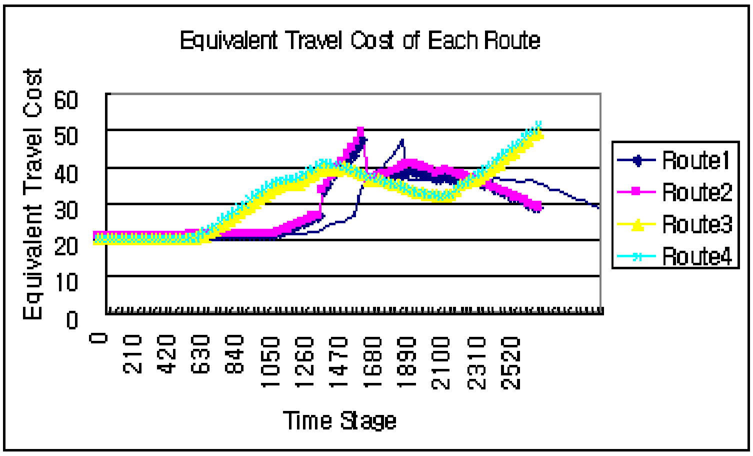

Figure 8. Equivalent Travel Cost of Each Route(Before DFS)

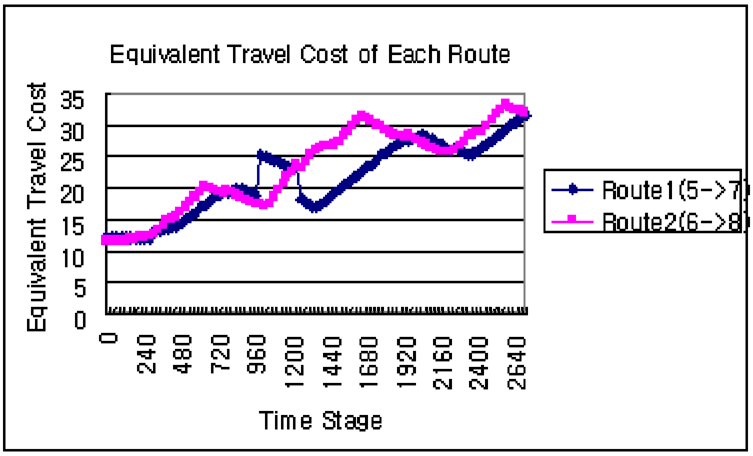

Figure 9. Equivalent Travel Cost of Each Route

4.3 Assess the effectiveness of DFS

To assess the effectiveness of DFS, we analyze the changes of link delay time after multi-class dynamic traffic assignment. At first, <Fig. 10> shows the overall link delay time before DFS and we get to know that the delay time increase to 1,111sec because of accident at link 5. But <Fig. 11> shows that it has lower delay time compared with <Fig. 10> that expresses the overall link delay time after DFS.

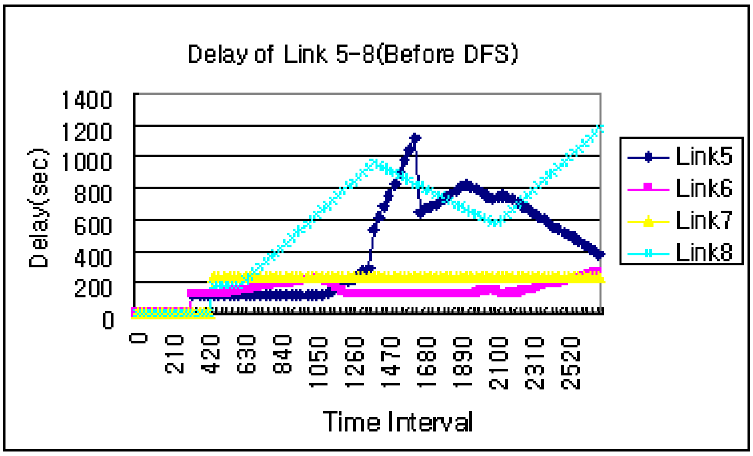

Figure 10. Delay Time Of Each Link(Before DFS)

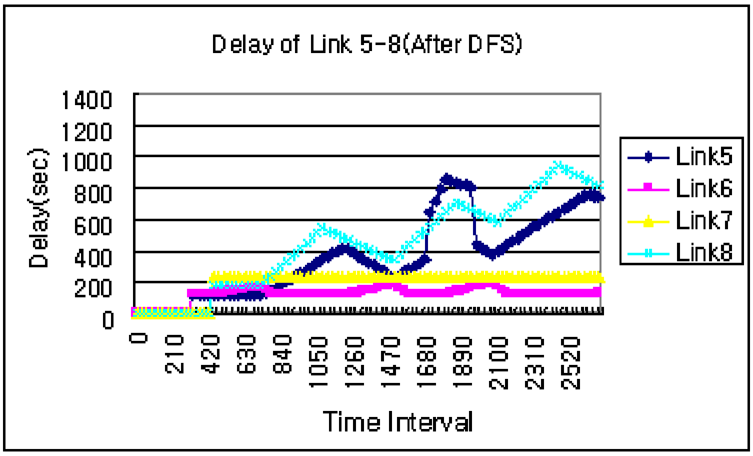

Figure 11. Delay Time Of Each Link(After DFS)

By studying the application of DFS within the sample network used in this study using a multi-class dynamic traffic assignment, we get to know that the sum of average travel time of each link decreases from 177,322 before DFS to 159,359 after DFS and there is a 10% improvement effect. There is great effect in the aspects of total travel time which travelers experience, so total travel time decrease from 2,510,601sec before DFS to 2,202,583sec after DFS. This difference corresponds to 12% improvement effect.

Ⅴ. CONCLUSION AND FURTHER RESEARHCES

In this study, dynamic multi-class traffic assignment model combined with traffic information service model is developed, in order to measure the effect of providing traffic information that is core element in ITS. Through this model was applied to toy network, dynamic route guidance strategy was evaluated.

Dynamic route guidance strategy was consisted of a strategy that shortest path information is provided to traveler through real-time path finding, and a strategy that traffic is disperse to complete network equilibrium condition through solving the objective function. This dynamic assignment model was developed to consider the behavior of traveler's rerouting, through the traffic information, provide to traveler, is proved not only before driving, but in driving through in-vehicle equipment.

In order to develop the model, RHI(Rolling Horizon Implementation) was utilized to dynamic multi-class assignment. At the same time, roll period and rest period was set up to consider the information renewal period. And all travelers were classified 3 groups by the feature of information provided. The real time traffic information utilized in dynamic route guidance strategy is assumed as instantaneous traffic information.

The traveler groups were classified as;

1) The traveler groups that don't have any traffic information (the traveler group 1)

2) The traveler groups that receive the real time shortest path information continually in driving as well as before driving. (the traveler group 2)

3) The group to which the specific route was provided individually for network equilibrium (the traveler group 3)

This paper proposed a multi-class dynamic traffic assignment and applied it to an example network for assessing the application of DFS out of traffic information providing strategies. Despite the travelers have diverse communication equipments such as in-vehicle equipment, VMS, Internet, ARS, PDA, and Cell phone, we focused on the travelers who use in-vehicle equipment generally to receive traffic information. The multi-class dynamic traffic assignment consists of three groups and performed with RHI.

By investigating the application of DFS within the sample network we found that the sum of average travel time of each link decreases from 177,322 to 159,359 after DFS, which amounts 10% improvement. There is also significant improvement from the aspect of total travel time travelers experienced, that it decreases from 2,510,601sec to 2,202,583sec, which corresponds to 12% improvement.

This study is implemented including of many assumption for carrying out them side by side construction of dynamic multi-class traffic assignment model and evaluation of dynamic route guidance strategy. Therefore if that assumption is realized various dynamic route guidance strategy is more effective

We are able to analysis reduction of road congestion on account of effective real-time traffic information in use of dynamic multi-class traffic assignment and cope with especially nonrecurrent traffic congestion situation providing real-time traffic information

In conclusion this study can advance present traffic information providing system and proposed proper traffic information strategy satisfy both traveler and transportation operator

There remain several further researches, which includes followings.
- Expansion to a large network and application to real study area
- Analysis according to accident situation and durable time of accident
- Testing several control variables involving ITS measures
-Expansion the model to a variable demand one

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